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Comparison of a conventional municipal plant, and an MBR plant with and without MPE

A comparison of the environmental and financial performance of a conventional activated sludge (CAS) plant, membrane bio-reactor (MBR), and MBR treated with Nalco Membrane Performance Enhancer (MPE technology, in the treatment of municipal wastewater

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ABSTRACT

Wastewater treatment using submerged membranes has become an industry standard treatment technology over the last 15 years. Initially, membrane bio-reactor (MBR) plants were often built in regions with the highest effluent quality requirements or in areas of water scarcity. MBR systems have increasingly gained acceptance as one of the best wastewater treatment technologies available. Globally, MBR technology is the fastest growing wastewater treatment technology available, with an annual growth rate (depending upon the country) of between 10 and 20%.

Keywords: MBR; Fouling; Flux; Peak flow; Permeability; EPS; Reduction of fouling; Operation costs; Investment costs; Wastewater treatment; Membrane; Zero liquid discharge; Water reuse

The main justification behind the decision to build an membrane bio-reactor (MBR) plant can include:

- The development of water reuse opportunities.
- The use of good quality MBR effluent as “pre-treatment” for further steps such as reverse osmosis.
- 100% efficiency in solid/liquid separation.
- High-quality effluent with minimised environmental impact.
- Low physical footprint (<40% of a conventional activated sludge [CAS] plant).
- Ability to directly reuse plant effluent for irrigation, cleaning, industrial process water supply, cooling tower makeup and many others.
- Ease of future plant expansion due to modularity.

Treated municipal wastewater is often discharged into sensitive rivers or lakes, and this requires municipalities to meet very stringent treatment standards. All impurities have to be removed in order to protect the surface water environment. In tourist areas, MBR plants are used to ensure a water quality acceptable for discharge into waters where people can swim. To date, about 60% of all MBR plants have been built in industrial applications, but in most cases these plants are discharging their treated effluent into the sewers of the local municipality for further treatment. Industrial customers usually invest in an MBR plant because of financial or legal reasons. Fig. 1 shows the growth in the market for MBR technology during the past 20 years.

The main drivers for industrial companies to invest in MBR technology are:

- The need to meet discharge limits according to local legislation.
- Avoidance of penalties from discharging polluted wastewater.
- Limited availability of freshwater resources.
- Independence from public water supplies.
- Financial reasons.
- No or little available space for plant construction.
- Need to upgrade an existing plant by retrofitting newer technology.

More than 5,000 MBR plants are now in operation around the world. Much work has already been carried out regarding research and optimisation to reduce the captail expenditure or investment costs (CAPEX) and operation expenditures or operation costs (OPEX) of this technology, to make it more competitive and available for use in other applications. However, more than 80% of global research activities on MBR operation are focused upon the reduction of problems caused by fouling.

Many different actions have been taken to reduce and optimise equipment and operational costs. A major focus has been the reduction of membrane costs. Besides the higher overall equipment costs, membrane costs have been the main cost driver regarding OPEX (e.g. short lifetime vs. high replacement costs). During the last 20 years, the costs for installed membranes have been greatly optimised, starting at an historical high of >$400/m^2$ down to now <$80/m^2$ depending upon the kind of system. Fig. 2 shows the decreasing trend in the cost of MBR plants since 1992. The major reductions are clearly shown for membrane replacement costs and for the amortisation of capital.

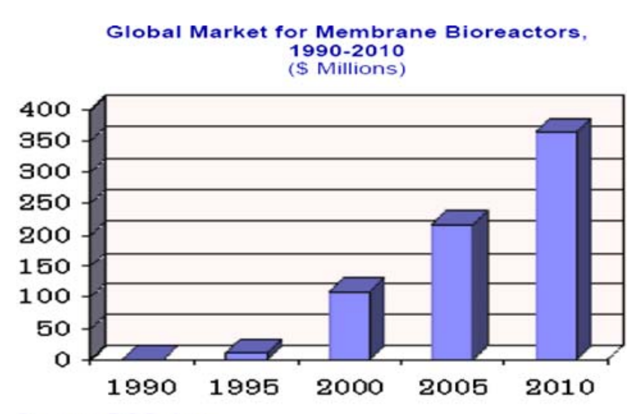


Fig. 1. MBR market size 1990–2010.

During the past 10 years, there has been little further innovation to deliver major reduction or optimisation of these costs. Therefore, it has become necessary to search for new opportunities to reduce the CAPEX and OPEX of an MBR plant, but without reducing quality and compromising safe and reliable operation. In Fig. 3, the different cost elements for an MBR plant are shown.

It is clear from the data presented in Figs. 2 and 3 that the costs regarding equipment acquisition (amortisation and investment) are major cost drivers. Compared to CAS plants, the period of amortisation is shorter because a bigger part of the investment cost is related to mechanical equipment, membranes and electrical engineering instead of civil engineering.

Therefore, the target to improve the competitiveness of an MBR system must optimise all aspects of the system where possible. To explain the steps Nalco has taken to address these issues, it is necessary here to go into some detail. Over six years ago, Nalco started to identify opportunities and innovation which would optimise the performance of an MBR system, and significantly reduce CAPEX and OPEX expenditures.

In this paper, the strategy used to identify areas for improvement, and the technology which was developed and applied as a consequence, are described and illustrated by means of a calculation model. The calculation and comparisons are presented using the example of municipal wastewater. Industrial cases are not generally comparable, and often unique, therefore it was felt more informative to use municipal wastewater conditions for this particular example. This comparison is done as a theoretical calculation using design conditions and operation experiences of erected plants. The calculation is based on tendered projects.

1. Introduction

The major cost drivers for MBR equipment are the equipment itself plus the costs of the membrane. These components are usually sized according to specific hydraulic conditions:

- Membranes
- Permeate pumps
- Pipework
- Cross-flow blowers
- Drainage equipment
- Control equipment

The size of the tanks, fine bubble aeration, pretreatment, chemical treatment, biological parameters,

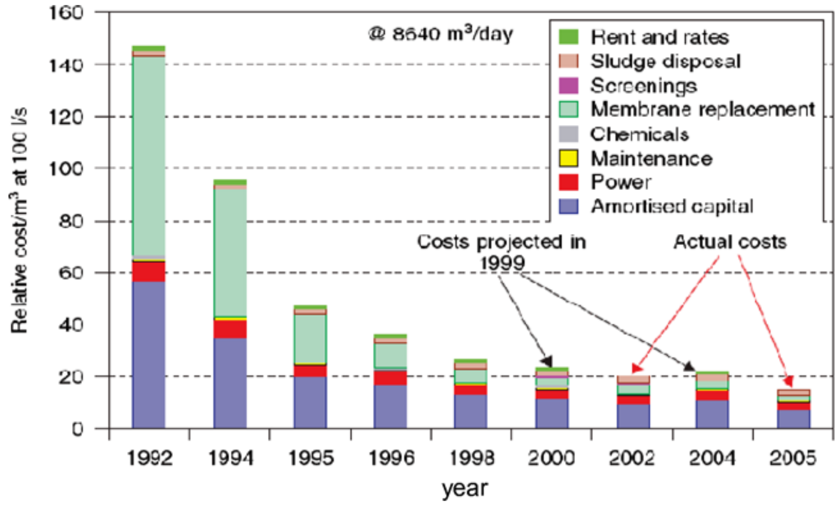


Fig. 2. Change in the total cost of MBR equipment and operations 1992–2005. Source: Ref. [11].

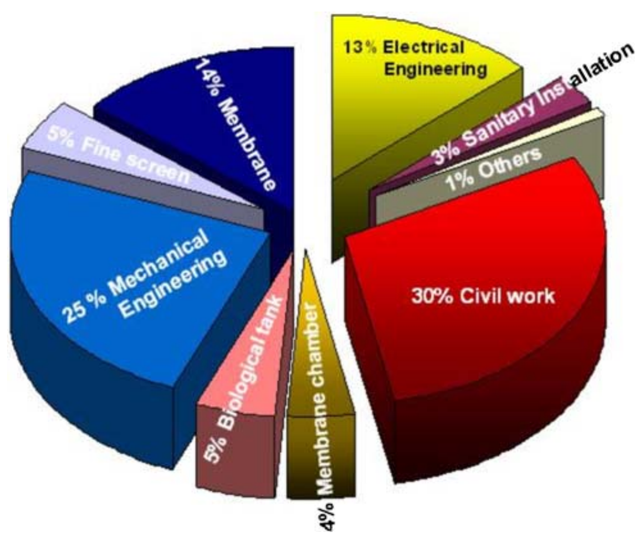


Fig. 3. MBR equipment costs—CAPEX.

recycling pumps and other components are mainly designed according to the incoming load on the system, and the quality of effluent required.

This brief summary shows that three major factors are responsible for the design, size and overall cost of a wastewater treatment plant:

- the physical and chemical loading of the incoming wastewater,
- the standard to which the wastewater must be treated in order to meet environmental standards, and
- the hydraulic conditions of the total system.

MBR plants have the advantage of a mixed liquor suspended solids (MLSS) concentration three to four times higher than the more traditional CAS plants, and therefore can produce the same or better results with a much smaller equipment footprint.

The main focus for innovation and optimisation has been on the hydraulic characteristics of the total system. Improvement of hydraulic characteristics can offer major cost reductions in the total cost of MBR systems when compared to CAS systems. Industrial companies very often recognise a greater financial benefit when deciding to use MBR technology. In general, the load can be higher, and the amount of water to be treated lower, when compared to municipal treatment plants, however in industrial cases the objectives of any treatment programme are somewhat broader. These can include a target to achieve high system availability, superior effluent quality to facilitate water reuse, flexibility and all with a smaller equipment footprint. Such treatment strategies are designed to ensure stable performance with less upsets, and operational characteristics, which can meet treatment standards under the range of conditions, expected.

The amount of membrane surface required is calculated based on the volume and flow of water, which must be treated. If the membranes become fouled, no water can be treated, so innovation too has focused upon the avoidance or mitigation of fouling.

2. Comparison

This paper shows the CAPEX and OPEX of a wastewater treatment plant under "normal" circumstances and also by using the Nalco Membrane Performance Enhancer (MPE) technology to improve the performance and competitiveness of an MBR plant [4–6].

The Membrane Performance Enhancer (MPE™) technology, developed by Nalco in 2002, is used in full-scale MBR plants to overcome upsets, to control/avoid fouling and also to enlarge the capacity of the MBR plant. These new innovative programmes coagulate the SMP (colloidal extra polymer substances [EPS], micro particles) and remove their chemical activity. The use of MPE™ technology has consistently shown that membrane fouling is significantly reduced even at higher fluxes and lower transmembrane pressures (TMPs). In addition, permeate chemical oxygen demand (COD) was reduced by ~30% with no negative effect on bioactivity. The oxygen transfer efficiency (α-factor) shows also a slight increase [7,8].

For more details and request for testing and trials, please contact your local Nalco agent.

In the following comparison, three different plants are presented. The first example uses a traditional CAS plant treating municipal wastewater, the second uses an MBR plant treating similar wastewater and the third is based upon a situation where Nalco technology was applied to improve the performance of the MBR plant (note that an exchange rate of €1 = $1.40 had been used for purposes of these calculations).

Summary of systems used in this comparison:

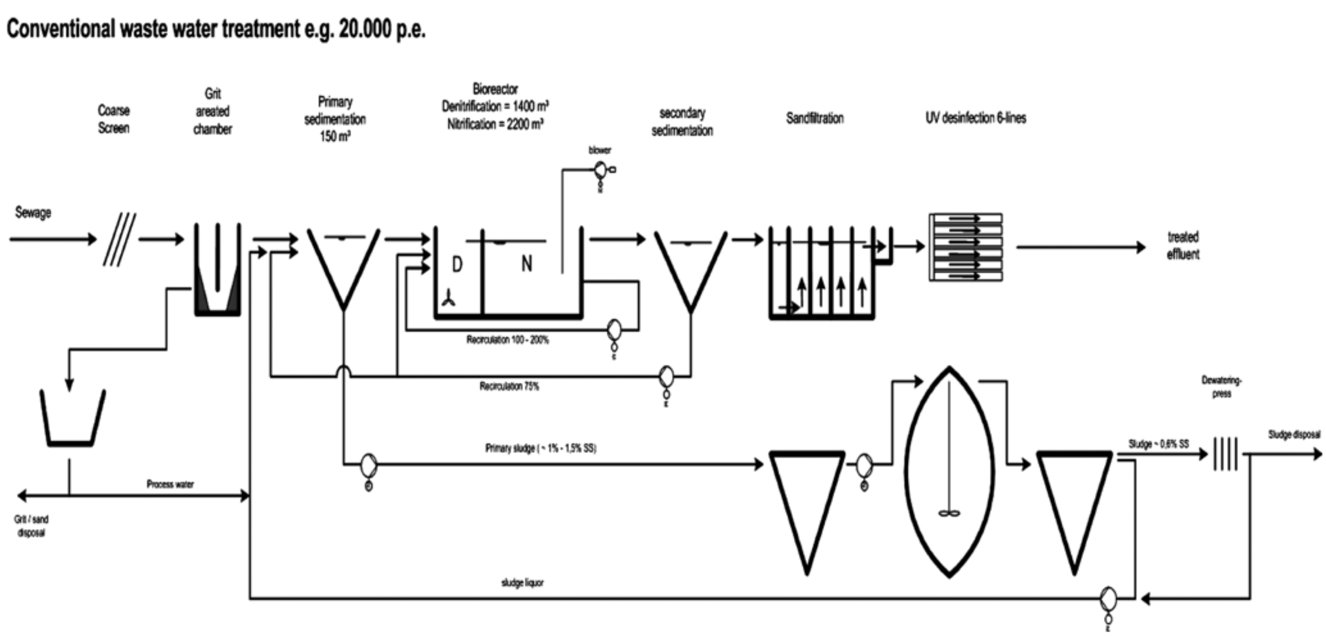
1. CAS plant including sand filtration + UV.
2. MBR plant designed and operated in the conventional way.
3. MBR plant using Nalco's MPE technology.

For the calculations and design, the same baseline figures (20,000 population equivalent [p.e.]) have been

Table 1
Baseline data for plant operation: characterisation of municipal wastewater

Amount of water (minimum flow)	1,500 m^3/d		0.528 mgd
Average daily flow	3,000 m^3/d		0.925 mgd
Daily peak flow (rain water, etc.)	4,000 m^3/d		1.057 mgd
Peak flow per hour (18 h/peak)	220 m^3/h		0.058 mgh
Water amount per year	1,050,000 m^3/a		3,330,215 mga
BOD	60 g/p.e. × d	1,200 kg/d	600 mg/l
COD	120 g/p.e. × d	2,400 kg/d	1,200 mg/l
TKN	11 g/p.e. × d	220 kg/d	110 mg/l
P_{tot}	2 g/p.e. × d	40 kg/d	20 mg/l

Sludge age ~ 9 days, 12°C, MLVSS = 3,400 mg/l + Inorganic solids ~400 mg/l = 3,800 mg/l.
Effluent quality: COD < 60 mg/l, BOD < 10 mg/l, NH_4–N < 1 mg/l, N_{tot}<15 mg/l, P_{tot} < 0.3 mg/l.



Picture 1. Layout of a typical CAS plant as used in this paper.

Table 2
CAPEX required for the build of the CAS plant

Step/unit	Specification	Machinery	Civil work	Electric/ measurement
Coarse screen 6 mm	2 Lines each 50% (110 m^3/h)	€90,000	€40,000	€40,000
Primary sedimentation	150 m^3, 1 circle tank	€45,000	€90,000	€30,000
Grit aerated chamber		€50,000	€ 80,000	€20,000
Denitrification	1,400 m^3, 2 lines	€85,000	€560,000	€80,000
Nitrification (incl. aeration)	2,200 m^3, 2 lines	€360,000	€850,000	€210,000
Secondary sedimentation	2,400 m^3, 2 rectangular tanks, $D = 20$ m	€320,000	€850,000	€180,000
2 Thickener	Each 500 m^3	€60,000	€420,000	€20,000
1 Digester	1,200 m^3	€80,000	€720,000	€50,000
2 Final thickener	Each 500 m^3	€60,000	€420,000	€20,000
Sludge dewatering press	Belt press (option)	€550,000	€60,000	€30,000
Sand filtration	15 $m^3/m^2 \times h$, four filters each 5 m^2	€240,000	€120,000	€60,000
UV-disinfection	6 lines, each 40 m^3/h	€180,000	€120,000	€60,000
Others, engineering etc.		€250,000	€500,000	€250,000
Sum		€2,370,000	€4,830,000	€1,050,000
Total CAPEX (including sludge treatment)		€8,250,000 €413/p.e.	$11,550,000 $522/p.e.	
Total CAPEX (without sludge treatment, only storage tank)		€6,260,000 €313/p.e.	$8,764,000 $438/p.e.	

used in order to permit like-for-like comparisons with the results obtained. A typical municipal wastewater was used (as shown in Table 1). In all cases, the plant design and operation is described in terms of high-level calculations. However behind each value, more detailed calculations including pipe dimensions, measurements, control systems, biological treatment performance, blower performance, and pumps and mixers have been included. Prices and costs typical of a wide range of tendered projects were used.

The calculation of the tank size for each example varied according to the local situation, so it is felt that the comparison is realistic and is based upon situations, which are typical in the field.

The cost calculation is using the same basic costs. Therefore, the comparison can be transferred also into regions where the price level is different. If there are significant differences between civil work and mechanical investment, the costs can be different. In this case, please see the detailed calculation to adjust the cost relation.

2.1. Plant example no. 1: conventional municipal activated sludge (CAS) plant

Picture 1.
Tables 2–6.

2.2. Plant example no. 2: municipal MBR plant

The design of a conventional MBR plant must take the most difficult operation periods into account to ensure always stable operation especially during maximum hydraulic peak, peak load, potential upsets and low temperature. Often additional lines are installed to ensure redundancy in case lines must be taken out of operation. This calculation impact is shown in Tables 7 and 8 (Picture 2).

Table 3
OPEX required for the municipal CAS plant

No.	Kind of costs	Consumption	Spare price	Annual costs (€)
1	Personal costs, workers	Similar in all cases		
2	Energy costs (coarse screen, pre-sedimentation, denitrification, bio-reactor, secondary sedimentation, sand filtration, UV, sludge treatment, others)	365,000 kW/a	€0.09/kWh	€32,900/a
3	Chemical costs (P-removal, cleaning, sludge dewatering)			€25,000 €/a
4	Sludge disposal costs	Similar in all cases		
5	Maintenance costs			
	Civil work	0.5% CAPEX		€24,200/a
	Machinery	2.0% CAPEX		€96,600/a
	Electric/measurement	2.0% CAPEX		€22,000/a
6	UV-lamp replacement (lifetime 2–3 years, filter maintenance)			€42,500/a
7	Others	Overall		€10,000/a
Sum (only for comparison: additional annual costs)		OPEX		€253,200/a

Table 4
Design figures for MBR

Sludge age ~20 days, 12°C, MLSS = 12,000 mg/l + Inorganic solids = 12,400 mg/l
Effluent quality: COD < 40 mg/l, BOD < 5 mg/l, NH_4–N < 1 mg/l, N_{tot} < 5 mg/l, P_{tot} < 0,3 mg/l

2.3. Plant example no. 3: municipal MBR plant + MPE technology

MBR plants are particularly affected by fouling and upset during cold temperatures [4,7,10], and during shock events, which results in lower flux rates and requires more membranes. Often system availability is decreased. Under such conditions, it is essential to optimise operating conditions, reduce fouling and continuously enhance the performance of the membrane systems. In identifying successful solutions to these challenges, there are several main benefits to be realised:

- Reduction of energy demand and costs.
- Reduction of down time.
- Enhanced asset lifetime.
- Fewer operational problems.
- Improved oxygen transfer efficiency (~15%).
- Foam reduction.

In this example, the calculation was done based upon Nalco's experience with operational CAS plants and conventional MBR plants. Depending on the kind of membrane used, results can vary, however this had no discernible impact on the results of the comparisons made. At the end of this paper, an evaluation of costs and their variation is presented for information (see Table 12). For some MBR plants, their lifetime is lower than 8 years because of the necessary high cleaning frequency and mechanical stress, for example high TMP. A major target was to reduce chemical cleaning frequency and to reduce the TMP during plant operation.

In Picture 3, flux data are shown for ~20 municipal MBR plants using the MPE technology. Based on these experiences, the peak and average flow can be fixed and used for the design of a new MBR plant [2,3].

Compared to the design flux rates of conventional MBR plants, the peak and average flux rates when using the Nalco MPE technology were approximately 30 to 100% higher. The experiences using MPE technology led to reduced chemical cleaning frequency, less equipment and maintenance costs, lower membrane replacement costs, less upsets and a stable reliable operation. Reliability is very often a major reason to spend additional money on more membranes and more control and measurement equipment. The drawbacks are usually higher costs and reduced competitiveness. Traditional chemicals for sludge dewatering or chemicals for pre-treatment in normal use can have

Table 5
CAPEX of the MBR plant without MPE

Step/unit	Specification	Machinery	Civil work	Electric/ measurement
Coarse screen 6 mm	2 Lines each 50% (110 m^3/h)	€90,000	€40,000	€40,000
Fine screen < 1 mm	2 Lines each 50% (110 m^3/h)	€100,000	€40,000	€30,000
Primary sedimentation	150 m^3, 1 circle tank	€45,000	€90,000	€30,000
Grit aerated chamber		€50,000	€80,000	€20,000
Denitrification	480 m^3, 2 lines	€35,000	€260,000	€50,000
Nitrification (incl. Aeration)	700 m^3, 2 lines	€180,000	€340,000	€210,000
Membranes, blowers, permeate pumps	7,480 m^2, 3 lines, ×190 m^3 (calculated 50% nitrification)	€1,180,000	€320,000	€180,000
2 Thickeners	Each 300 m^3	€60,000	€280,000	€20,000
1 Digester	1,000 m^3	€80,000	€620,000	€50,000
2 Final thickeners	Each 300 m^3	€60,000	€420,000	€20,000
Sludge dewatering press	Belt press (option)	€550,000	€60,000	€30,000
Others, engineering, etc.		€250,000	€500,000	€250,000
Sum		€2,680,000	€3,050,000	€930,000
Total CAPEX (including sludge treatment)		€6,660,000		$9,324,000
		€340/p.e.		$476/p.e.
Total CAPEX (without sludge treatment, only storage tank)		€4,770,000		$6,678,000
		€246/p.e.		$343/p.e.

Table 6
OPEX of the MBR plant without MPE

No.	Kind of costs	Consumption	Spare price	Annual costs (€)
1	Personal costs, workers	Similar in all cases		
2	Energy costs (coarse screen, pre-sedimentation, denitrification, bio-reactor, MBR, sludge treatment, others)	795,000 kW/a	0.09/kWh	€87,900/a
3	Chemical costs (P-removal, cleaning, sludge dewatering)			€37,000/a
4	Sludge disposal costs	Similar in all cases		
5	Maintenance costs			
	Civil work	0.5% CAPEX		€15,300/a
	Machinery (without membrane replacement)	2.0% CAPEX		€39,600/a
	Electric/measurement	2.0% CAPEX		€17,400/a
6	Membrane replacement costs (8a lifetime)	1,000 m^2/a	€90/m^2	€90,000/a
7	Others	Overall		€10,000/a
	Sum (only for comparison: additional annual costs)	OPEX		€297,200/a

a negative impact on membrane performance. In the MBR technology, it was necessary only to use chemicals and biomass, which are adapted for an MBR plant for pre-treatment, biological compartment, membrane performance and sludge dewatering.

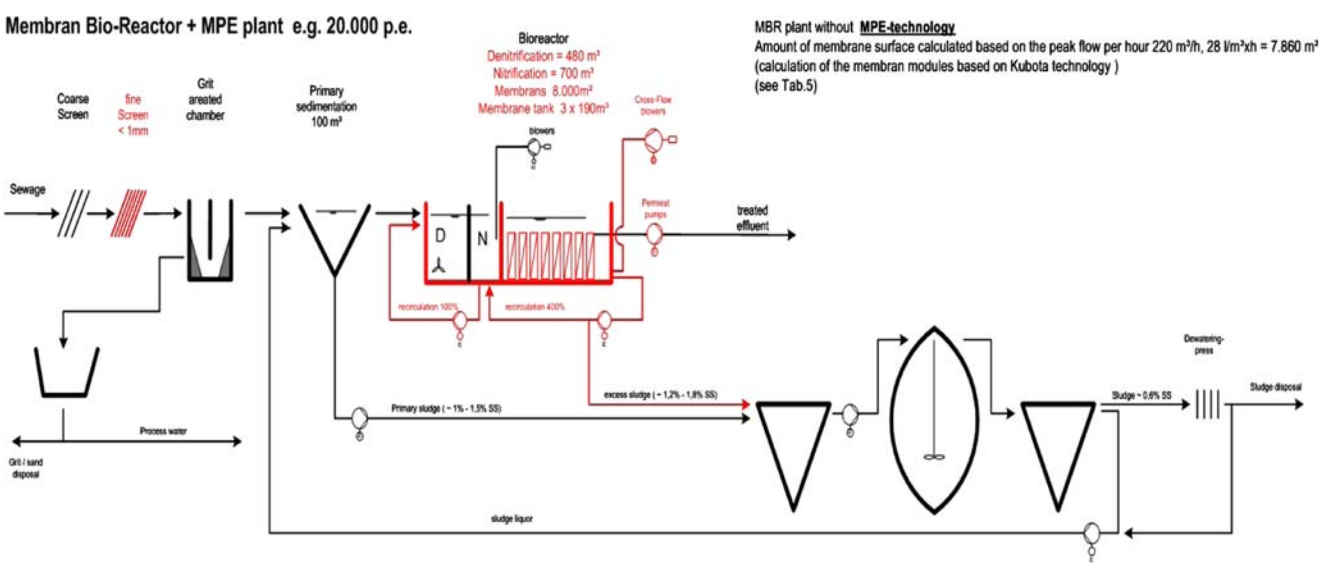
Nalco MPE is a modified polymer with partial cationic charge. MPE complexes and precipitates the negatively charged biopolymers (EPS like polysaccharides and proteins), which are known to be a major foulant in MBRs. MPE also helps to increase the cake layer porosity [1,5] on the membrane surface. A third action of MPE is that the particle size increases and therefore minimises the fouling caused by colloidal particles.

Table 7
Design *without* MPE case would require 7,340 m^2 membrane

Period	Peak inflow (m^3/h)	Temperature (min) (°C)	Flux (L/[m^2 h])	A membrane (m^2)
Hour	220 m^3/h	10	28	*7,860*
Day	167 m^3/h (4,000 m^3/d)	10	28	6,000
Week	146 m^3/h (3,500 m^3/d)	10	24	6,100
Month	125 m^3/h (3,000 m^3/d)	12	21	5,950
Average	120 m^3/h (1,050,000 m^3/a)	14	17	7,060

Table 8
Design + *MPE* case would require 5,460 m^2 membrane

Period	Peak inflow	Temperature (min) (°C)	Flux (L/(m^2 h])	A membrane (m^2)
Hour	220 m^3/h	10	48	4,600
Day	167 m^3/h (4,000 m^3/d)	10	38	4,400
Week	146 m^3/h (3,500 m^3/d)	10	34	4,300
Month	125 m^3/h (3,000 m^3/d)	12	26	4,800
Average	120 /h (1,050,000 m^3/a)	14	22	*5,460*



Picture 2. Layout of a typical MBR plant (without Nalco MPE).

Benefits of MPE technology:

- Increase the particle size.
- Increase the filterability (up to 800% possible).
- Promote higher back transport velocity.
- Ensure that the membranes could be kept clean during operation.
- Increase biofilm porosity.
- Reduce biofilm thickness.
- Increase the viscosity.

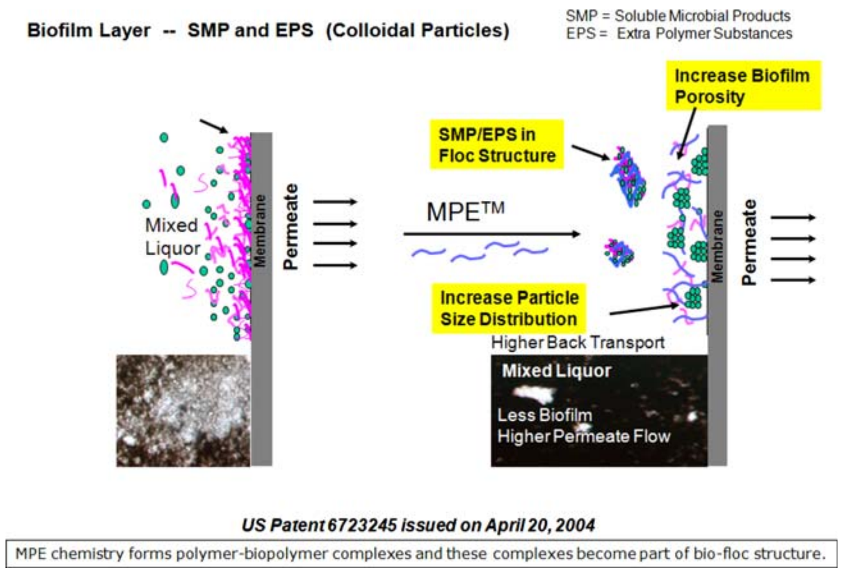


Table 9
CAPEX of the MBR plant + MPE

Step/unit	Specification	Machinery	Civil work	Electric/ measurement
Coarse screen 6 mm	2 Lines each 50% (110 m^3/h)	€90,000	€40,000	€40,000
Fine screen < 1 mm	2 Lines each 50% (110 m^3/h)	€100,000	€40,000	€30,000
Primary sedimentation	150 m^3, 1 circle tank	€45,000	€90,000	€30,000
Grit aerated chamber		€50,000	€80,000	€20,000
Denitrification	480 m^3, 2 lines	€35,000	€260,000	€50,000
Nitrification (incl. aeration)	700 m^3, 2 lines	€180,000	€340,000	€210,000
Membranes	5460 m^2, 2 lines, x 190 m^3 (calculated 50% nitrification)	€840,000	€220,000	€170,000
2 Thickeners	Each 300 m^3	€60,000	€280,000	€20,000
1 Digester	1,000 m^3	€80,000	€620,000	€50,000
2 Final thickeners	Each 300 m^3	€60,000	€420,000	€20,000
Sludge dewatering press	Belt press (option)	€550,000	€60,000	€30,000
Others, engineering, etc.		€230,000	€480,000	€240,000
Sum		€2,320,000	€2,930,000	€910,000
Total CAPEX (including sludge treatment)		€6,160,000		$8,624,000
		€307/p.e.		$429/p.e.
Total CAPEX (without sludge treatment, only storage tank)		€4,270,000		$5,990,000
		€212/p.e.		$297/p.e.

Target: Reduction of the investment costs (CAPEX)
Reduction of the operation costs (OPEX)
Solving typical operation problems (cold temperature, EPS, etc.).

MPE50 has always shown a measurable effect on the floc characteristics by altering the porosity [1], thus improving filterability and reducing fouling [9] potential. Following addition of the polymer, smaller particles in the <15 μm range bind together to form larger flocs. As a result, flux rates are increasing as shown in Picture 3. Especially in case of low temperature at municipal plants, this is a beneficial effect [4].

Table 10
OPEX of the MBR plant + MPE

No.	Kind of costs	Consumption	Spare price	Annual costs [€]
1	Personal costs, workers	Similar in all cases		
2	Energy costs (coarse screen, pre-sedimentation, denitrification, bio-reactor, MBR, sludge treatment, others)	635,000 kW/a	€0.09/kWh	€57,200/a
3	Chemical costs (*P*-removal, cleaning, sludge dewatering, MPE treatment)			€57,000/a
4	Sludge disposal costs	Similar in all cases		
5	Maintenance costs			
	Civil work	0.5% CAPEX		€14,600/a
	Machinery (without membrane replacement)	2.0% CAPEX		€33,700/a
	Electric/measurement	2.0% CAPEX		€16,600/a
6	Membrane replacement costs (10a lifetime)	550 m^2/a	€90/m^2	€49,500/a
7	Others	Overall		€10,000/a
	Sum (only for comparison: additional annual costs)	OPEX		€238,600/a

Table 11
Summary of CAPEX and OPEX for all three options

	CAPEX		%	OPEX	%
Conventional activated sludge plant	€8,250,000	($11,550,000)	100	€253,200/a*	100
– without sludge treatment	€6,260,000	($8,764,000)	100	$350,280	
MBR plant without MPE	€6,800,000	($9,520,000)	82	€297,200/a*	
– without sludge treatment	€4,910,000	($6,874,000)	78	$430,080	117
MBR plant + MPE	€6,160,000	($8,622,000)	75	€238,600/a*	
– without sludge treatment	€4,270,000	($5,990,000)	68	$348,040	94

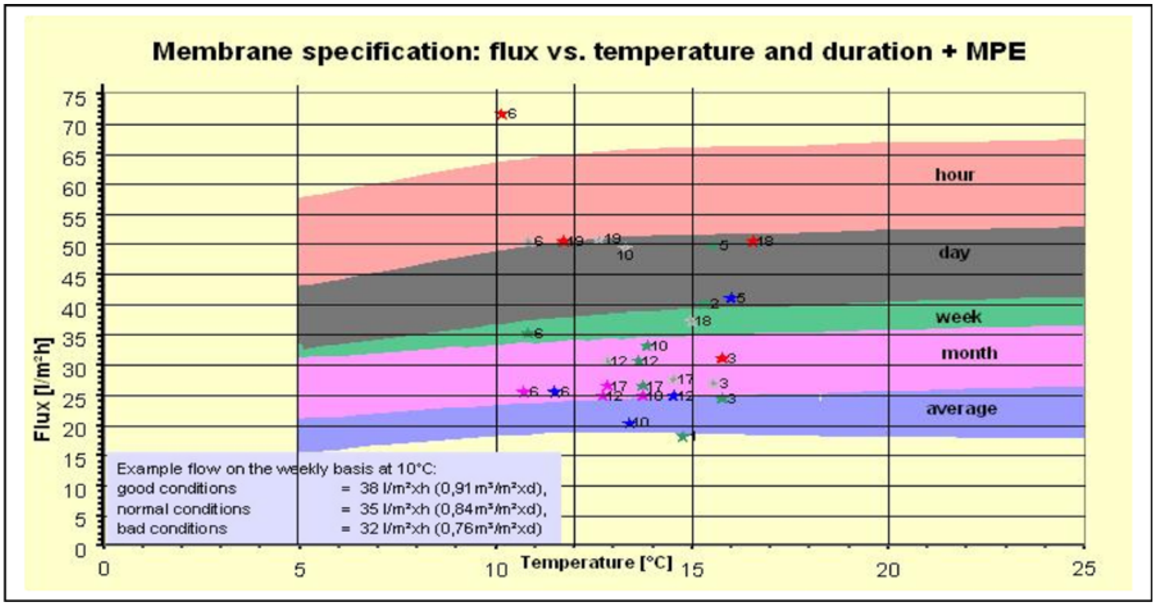
Note: *OPEX are calculated including sludge treatment (no disposal costs).

Table 12
Total annual costs **including depreciation

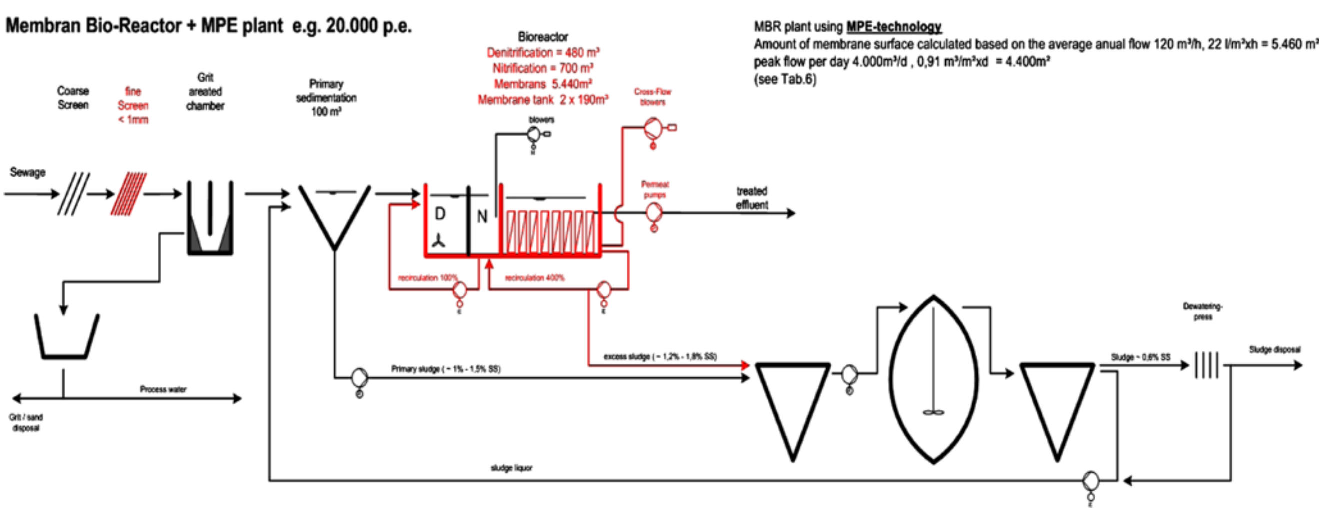
	Linear depreciation, CAPEX					
	Machinery	Civil work	Electric	OPEX	Total annual costs	%
	8 years	20 years	5 years			
CAS	€296,250	€241,500	€210,000	€253,200	€10,10,000/a	100
MBR	€269,500*	€152,500	€186,000	€297,200	€905,200/a	89.6
MBR + MPE	€228,500*	€146,500	€182,000	€238,600/a	€795,600/a	78.7

*Without membrane costs, membrane replacement costs are operation costs.

**Including sludge treatment.



Picture 3. Design flux graph for municipal MBR plants using the MPE technology.



Picture 4. Layout of the MBR plant + Nalco MPE.

The impact on CAPEX and OPEX is shown in this comparison.

2.4. Plant example no. 3: municipal MBR plant + MPE technology

Picture 4.

Tables 9–11.

3. Comparison summary

This comparison shows the costs of a plant able to treat a maximum of 4,000 m^3/day of municipal wastewater. This is a specific wastewater production of 200 l/p.e. × d including leakage water and a certain amount of rainwater. These design figures will vary by country due to the local situation and requirements. The data in this paper give an indication of the relative price levels, all things being equal.

The comparisons show clearly the financial advantages of a newly erected MBR plant over a traditional CAS plant. In a situation where land prices are relatively high, the costs for a CAS plant will inevitably increase due to the relatively large equipment footprint. It also shows that there is a clear advantage for MBR technology to be used with Nalco's MPE technology.

In case of a CAS + SF + UV, it must be taken into account that the bacteria and viruses are only destroyed but not removed. An MBR plant is a 100% barrier for all micro pollutants and separating bacteria and >99.9% of viruses.

This example has shown that, based upon experiences with actual systems, that using MPE technology makes MBR systems more competitive and cheaper compared to CAS systems. Using MPE technology in this specific case gave a benefit of about €110,000/a.

This saves about 0.10€/m^3 (\$0.14/m^3) costs at >1,000,000 m^3/a compared to a CAS plant.

References

[1] Yoon et al., Effects of flux enhancing polymer on the characteristics of sludge in membrane bioreactor process, Water Sci. Technol. 51(6–7) (2005) 151–157.

[2] Collins et al., Reduction of capital and operating costs of membrane bioreactor using modified polymers, 10/2007, IDA world congress at Maspalomas, Gran Canaria, Spain.

[3] Byung-Kook Hwang, Woo-Nyoung Lee, Pyung-Kyu park, Chung-Hak lee, In-Soung Chang et al., Effect of membrane fouling reducer on cake structure and membrane permeability in membrane bioreactor, 2007. Available from: www.sciencedirect.com.

[4] T. Murakami, H. Itokawa, Influence of Polymer Addition on Flux and Biological Performance of a Municipal Membrane Bioreactor, C Thiemig (Institute of Environmental Engineering ISA, RWTH Aachen University), (R&TD department Japan Sewage Works Agency).

[5] I.-S. Chang, C.-H. Lee, K.-H. Ahn, Membrane filtration characteristics in membrane-coupled activated sludge system—the effect of floc structure on membrane fouling, Sep. Sci. Technol. 34 (1999) 1743–1758.

[6] S. Yoon, J. Collins, D. Musale, S. Sundararajan, S. Tsai, A. Hallsby, J. Kong, J. Koppes, P. Cachia, Effects of flux enhancing polymer on the characteristics of sludge in membrane bioreactor process, IWA's Water Environment and Membrane Technology Conference, Seoul, Korea, 2004.

[7] S. Yoon, J. Collins, D. Musale, S. Sundararajan, S. Tsai, A. Hallsby, J. Kong, J. Koppes, P. Cachia, D. Chung, K. Kronoveter, Application of membrane performance enhancer (MPE) for full scale membrane bioreactors, IWA's Water Environment and Membrane Technology Conference, Seoul, Korea, 2004.

[8] P. Cornel, M. Wagner, S. Krause, Investigation of oxygen transfer rates in full scale membrane bioreactors, IWA Annual Conference, Melbourne, Australia, 2002 (e21291a).

[9] N. Cicek, W. Yang, University of Manitoba, Canada, trends in world-wide membrane bioreactor research, Presented at the Final MBR Workshop, Berlin, Germany, 2002 (03/2009).

[10] Thomas Wozniak, Nalco company "MBR design and operation using MPE technology", Presented at the IDA World Congress, Dubai, UAE (11/2009).

[11] F. Varidakis, Kubota membrane Europe Ltd. Kubota MBR technology Overview and applications in Greece presented at the MBR Congress at Thessalonica, Greece, (03/2009).